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The Paleoecology of Dome Creek Meadow, Bear River Corridor, Garfield County, Colorado.

By

Eric J. Feiler[1] and R. Scott Anderson[1,2]

[1]Quaternary Studies Program
Northern Arizona University
Flagstaff, Az 86011

[2]Environmental Sciences Program
Northern Arizona University
Flagstaff, Az 86011

Submitted To

Sue Struthers and Jeff Overturf
Routt National Forest
28587 W. US 40
Suite 20
Steamboat Springs, Colorado

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Abstract

A sediment core from Dome Creek Meadow provides proxy data for the last 10,600 years of environmental change in the Bear River Corridor. (BRC) Changes in pollen stratigraphy, macrofossil abundance, and sediment stratigraphy document at least four major shifts in environmental conditions. The oldest levels of the core document cool-dry, periglacial conditions followed by the establishment of a closed spruce-fir forest around the site. The middle Holocene witnessed a major change in the local forest community, probably due to increased temperature. The forest surrounding the site opened up, either in response to shifts in sensitive taxa, or in response to some other variable, possibly disease or insect predation. The late Holocene is characterized by a return to a closed spruce-fir forest. Data from the Dome Creek Meadow core also document at least one spruce bark beetle (Dendroctonus rufipennis) infestation (late Holocene) and suggest the possibility of insect infestation as an important factor in middle Holocene forest dynamics. The correlation of the basal date of the core and the glacial geology that formed the meadow indicate that the Dome Creek record is potentially out of phase with other Colorado Holocene glacial chronologies. While the Dome Creek meadow core provides only preliminary data relative to these issues, the potential for additional studies in the BRC is vast, as the number of potential sites with sensitive records in and around the BRC is large.

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Introduction

This project was initiated under a Challenge Cost Share Agreement between Northern Arizona University and the Routt National Forest. Its purpose was to provide a paleoecological reconstruction for the Bear River Corridor (BRC). This data could then be used to help interpret the significant cultural and paleontological resources recently located in the BRC.

While several paleoecological studies have been completed from sites at similar elevations in southern and central Colorado, few northern Colorado localities have been investigated. This report presents the results of analysis on a sediment core taken from Dome Creek Meadow, which lies within the BRC. This record, while fulfilling the goals of the cooperative agreement, also documents the first evidence for environmental change on the White River Plateau. Plant macrofossil, sediment stratigraphy, and pollen data from the core document a continuous record of environmental change over the last 10,600 years.

Background

Regional Paleoecology:

Late Pleistocene and Holocene paleoenvironments have been documented at several sites in the southern Rockies of Colorado. Glacial chronologies, as well as pollen and plant macrofossil localities provide proxy data for the last 15,000 years. Only one site from the Front Range of Colorado (Legg and Baker, 1980; Madole, 1986) records full glacial environments (ca. 25,000-17,000 yr BP).

The majority of palynological studies at high elevation sites in Colorado have attempted to reconstruct climate and environment by tracking changes in upper and lower treeline using a ratio of pine and spruce pollen (e.g. Maher, 1963), as well as presence/absence of spruce and fir as macrofossils at locations currently above timberline. Glacial chronologies document major and minor readvances which are directly linked to increases in effective precipitation (predominantly winter), and not necessarily to fluctuations in temperature.

Full Wisconsin glacial environments are documented at Lake Devlin, in the Front Range of Colorado (Legg and Baker, 1980). High Artemisia (sagebrush, wormwood) pollen percentages associated with low Picea (spruce) percentages suggest a cool and dry, tundra environment between 23,000 and 15,000 yr BP. Maximum glacial advance is dated to 19,000 yr BP at this location. Tundra appears to have persisted until 10,000 to 11,000 yr BP

when additional records (Markgraf and Scott, 1981; Short, 1985) indicate a change to cool-moist conditions. This is reflected by the establishment of spruce and fir, which existed in a closed forest community at many locations (Carrara et al., 1984; Short, 1985).

These conditions persisted until the early middle Holocene (8000-6000 yr BP depending on location). Continental warming is indicated by elevated treelines during the mid-Holocene (Andrews et al., 1975; Petersen and Mehringer, 1976; Carrara et al., 1984). At certain locations, lower treeline expanded downward as well (Markgraf and Scott, 1981; Fall 1988), suggesting that the middle Holocene was also a time of increased precipitation. By ca. 4500 yr BP most records indicate a cooling from mid-Holocene temperatures, a subsequent reduction in the elevation of upper treeline (Andrews et al., 1975; Petersen and Mehringer, 1976; Carrara et al., 1984), and an advance of lower treeline to higher elevations (Markgraf and Scott, 1981). Conditions appear to have become very much like the present by at least 3000 yr BP (Andrews et. al., 1975; Carrara et. al., 1984; Short, 1985). Petersen and Mehringer (1976) document at least one brief increase in temperature at ca. 2500 yr BP based on an increase in upper treeline, and Short (1985) suggests the last 1000 years have become colder.

Regional Glacial Chronology:

Pleistocene glacial history of the Rocky Mountains has been documented in several locations. Most chronologies are based on

the original chronology established for the Wind River Mountains of Wyoming (Ray, 1939, 1940; Moss, 1951; Richmond, 1957, 1965; Birkeland et al., 1971; and Birkeland and Miller, 1973). Five main Pleistocene glaciations are documented which are correlated to the glacial chronologies of the upper Mississippi Valley and surrounding region. Originally the Wisconsin glaciation for the Rocky Mountains was divided into two separate glaciations, the earlier Bull Lake (>53,000 yr BP to 34,000 yr BP) and the final Pleistocene glaciation, the Pinedale (25,000 to ca. 11,000 B.P). Relatively new data has changed this chronology by assigning a pre-Wisconsin age (ca. 140-150,000 yr BP) to the earlier Bull Lake glaciation (Pierce et al., 1976; Pierce 1979).

Neoglaciation in the Wind River range was originally documented by the late Holocene Gannett Peak advance (correlated with the Little Ice Age) and the middle Holocene Temple Lake advance (Richmond, 1965). Again, new data has changed this chronology by the re-dating of glacial features. New dates on the Temple Lake moraine put its age as probably late Pleistocene (ca. 11,500-12,000 yr BP) and not early Neoglacial (Zielinski and Davis, 1987; Davis and Zielinski 1988). While this apparently leaves the Gannett Peak advance as the only evidence for Neoglacial activity in the Wind River Range, there is evidence that the Gannett Peak advance overlays older Neoglacial tills for which more obvious features are lacking (Burke and Birkland, 1983).

Atwood and Mather (1932) documented Pleistocene glaciations

in the San Juan Mountains of Colorado. More recent studies in the San Juans, namely those by Andrews et al. (1975), Leonard (1979), Maher (1961), and Richmond (1954) greatly refined the earlier work of Atwood and Mather. These studies indicate that the San Juan Mountains were deglaciated by ca. 15,000 yr BP. More protected cirques at higher elevations possibly held glacial ice until ca. 9000 yr BP (Andrews et al., 1975). There is no documented evidence for any Neoglacial advances in the San Juan Mountains (Carrara and Andrews, 1973; Petersen and Mehringer, 1976).

Closer to the project area, glacial chronologies have been developed for the Front Range, primarily in Rocky Mountain National Park (Ray, 1939, 1940; Richmond, 1957, 1960). Other studies include those of the Park Range and Front Range by Madole (1969, 1980, 1986), and of the Front Range by Benedict (1967, 1973), Mahaney (1972), and White (1971). These studies document at least three main Pleistocene glaciations. The latest Pleistocene glaciation, correlated to the Pinedale, reached maximum extent ca. 20,000 B.P, with deglaciation occurring sometime between 15,000 B.P and 12,000 B.P (Nelson et al., 1979; Madole, 1980, 1986).

Early Holocene and later Neoglacial advances are documented in several central Colorado sites including the Fourth of July Valley and Arapahoe Cirque, both located in the Front Range (White, 1971; Benedict, 1973). The most extensive Holocene glaciation, the Satanta Peak advance, is dated to ca. 9900 B.P

(Benedict, 1973). This date, considered to be a minimum limiting age, is taken from a basal sedge peat in a bog at the base of Satanta Peak, near the terminal moraine that dams Caribou Lake. Benedict believed that many Front Range cirques contain paired Satanta Peak moraines, suggesting a staggered advance. In the same study, Benedict suggested the possibility of a minor readvance dating to ca. 8000 yr BP based on the presence of clastic sediments stratigraphically above the basal peat correlated with the Satanta Peak advance.

The first Neoglacial activity, the Triple Lakes advance, is documented by terminal moraines that currently occur at timberline. Unfortunately, there is currently no consensus on the actual age of glacial deposits assigned to this advance. Initially dated between 4-5000 yr BP (Benedict, 1973), a more recent minimum limiting date places the advance at least 1400 years earlier (Davis and Waterman, 1979), and Birkeland and Shroba (1974) suggest a similar age to the Satanta Peak advance based on relative dating techniques.

Two other Neoglacial advances have been documented in the Front Range of Colorado. The Audubon advance is dated between 1850 and 950 yr BP, and is characterized by both rock glaciers and moraines (Mahaney, 1972; Benedict, 1973). The Arapaho Peak advance, although not dated, occurs in the highest elevation cirques where perennial snow still occurs. Benedict (1973) assigns a date of 100-300 yr BP to these deposits based on lichen growth and Historic records.

Regional Paleoclimatology:

The changes that are reflected by glacial, pollen, and macrofossil data suggest large-scale changes in the climatic factors that influence the environment of the southern Rocky Mountains. Currently, regional climate is controlled by the establishment of strong, moisture-laden westerlies, which sweep across the continental interior. The westerlies are attributed to the location of at least three pressure systems around the margins of the North America (Borchert, 1950; Harrington and Harman, 1991). Weak, seasonal high pressure systems in the Great Basin and the more stable, and semi-permanent Bermuda High located in the subtropical Atlantic, combine with the large low pressure systems in northern North America (the Alberta and the Aleutian Lows) to establish these strong westerlies along the middle latitudes of the United States. The westerlies are the strongest in the winter when the polar front expands, forcing the northernmost westerlies further south. This effectively concentrates the westerly airflow across middle latitudes of North America during winter months (Harrington and Harman, 1991).

Summer climatic patterns for the region develop when the predominant westerlies shift northward as the Polar front retreats. This is coupled with a northward shift in the influence of the Bermuda High. During the summer months portions of this area receive increased precipitation as moist air from the subtropical Atlantic is pumped into the mid-continent by the Bermuda High (Borchert, 1950; Bryson, 1980;

Harrington and Harman, 1991).

Postulated shifts in the relative location of these fronts have been used to explain the changes seen in the paleoenvironmental records from Colorado (Markgraf and Scott, 1981; Fall, 1988, COHMAP, 1988). As continental ice decreased during glaciation, the influence of the permanent high associated with the polar front decreased. Latitudinally depressed westerlies moved northward following the retreat of the Polar front. This correlates well with Colorado paleoenvironmental reconstructions that show increases in spruce-fir communities soon after deglaciation. Markgraf and Scott (1981) and Fall (1988) suggest that the middle Holocene saw this continued pattern with increased temperatures and maximum monsoonal influence. Increased temperature raised upper treeline, while increased precipitation allowed the lower limit of treeline to expand also. Evidence for neoglacial activity suggest that this pattern ended ca. 4-5000 yr BP. This date is supported by pollen and macrofossil evidence which show significant changes in regional assemblages near this time. Late Holocene cooling (from mid-Holocene temperatures), and reduction in precipitation can be correlated with a reversal of this trend (i.e. reduced influence of subtropical air masses coupled with increased influence of Pacific air masses).

The Project Area:

The Bear River drains the eastern edge of the Flat Tops

wilderness area. The Flat Tops form the northeasternmost portion of the White River Plateau, a subsection of the Southern Rocky Mountain physiographic provence (Fenneman, 1931). Average elevation for this portion of the Plateau is approximately 3050 m with many local summits exceeding 3660 m. The flat alpine summits for which this area is named, are formed primarily by early and middle Tertiary alluvial and eolian deposits, most notably the Browns Park Formation and the Bishop Conglomerate. These sediments overly much older Precambrian granites, schists, and gneisses (Ives, 1938; Richmond, 1957; Reider, 1971). Late Tertiary basalt flows of up to 460 m in depth, originating from vents near Trappers Lake and Shingle Peak (southwest of the study area), cap and rest uncomformably over these deposits (Reider, 1971).

Current landform maps of the BRC suggest that much of the area has undergone serious mass wasting events in the form of landslides (Miller, 1977). Our surface reconnaissance supports Reider's (1971) conclusions that portions of the White River Plateau were dissected by Pleistocene glaciers. Landforms initially identified as "landslide deposits" (Qls) within the BRC are in fact glacially-derived. The extent of these deposits indicates that significant portions of the BRC were heavily glaciated during the Pleistocene. Lack of recognition of the nature of these deposits has left them undated, and therefore no glacial chronology exists for this portion of the White River Plateau.

Vegetation zones defined for Colorado and the southern Rocky Mountains generally follow elevational and precipitation gradients (Ramaley, 1927; Marr, 1961). Four zones occur within the project area. Alpine tundra occurs in the highest elevations where low mid-summer temperatures inhibit tree growth. This zone normally occurs above 3400 m, but varies with latitude and aspect. Dwarf Salix (willows), Gramineae (grasses), Cyperaceae (sedges), and other herbaceous taxa dominate the vegetation.

The subalpine zone occurs between 2900 and 3400 m and is dominated mostly by Picea engelmannii (Engelmann spruce) and Abies lasiocarpa (subalpine fir). Pinus contorta var. latifolia (lodgepole pine) also occur in this zone but only rarely as pure stands. Pinus flexilis (limber pine) and Pinus aristata (bristlecone pine) are common members of the southern Rocky Mountain subalpine community at other locations, but do not occur in the project area.

The montane zone extends from the lower limit of the subalpine zone to lower treeline, an elevation usually determined by precipitation although aspect and edaphic factors are important. On the eastern slope of the Front Range of Colorado this elevation is approximately 1800 m where the montane forest grades into grasslands. In other areas of the southern Rockies this elevation is approximately 2700-2900 m. Higher montane elevations are dominated by lodgepole pine, Picea pungens (Colorado blue spruce), Pseudotsuga menziesii (douglas fir),

Pinus ponderosa (ponderosa pine), and Populus tremuloides (quaking aspen). Lower elevations of the montane zone, occurring near but not in the project area, support Pinus edulis (pinon pine), Juniperus osteosperma (Utah juniper), and J. monosperma (one-seed juniper). Several shrubby taxa including, Cercocarpus montanus (mountain mohagony), and Quercus gambelii (gambel or scrub oak) also occur in the lower elevation montane forest.

Artemisia steppe occurs below the lower treeline limit of the montane zone in the project area. This is an open environment dominated by Artemisia tridentata (big sagebrush), Chrysothamnus spp. (rabbitbrush), Purshia tridentata (bitterbrush), and numerous grasses. Although normally limited to lower elevations, this vegetation zone can extend upwards to relatively high elevations. In the BRC Artemisia steppe occurs at least as high as 3050 m on the south facing side of the drainage.

Data from regional weather stations indicate that precipitation is fairly evenly distributed throughout the year for this portion of the White River Plateau (Ecological Science and Snow Survey, 1989). Thus, the BRC is effected by both Pacific maritime air masses driven by the polar jet (winter dominant), and subtropical moisture associated with the northward extension of the Bermuda High (summer dominant). The BRC is in a unique position in that during the summer it lies very near the boundary between these two precipitation regimes, and is probably equally affected by both.

Dome Creek Meadow:

Dome Creek Meadow is located at an elevation of 3165 m. The sedge (Cyperaceae) meadow has formed behind a recessional moraine of undetermined age at the headwaters of Dome Creek, which is a tributary of the Bear River (Figure 1). The site is located within the subalpine vegetation zone and is surrounded by a dense engelmann spruce-subalpine fir forest. This area is currently recovering from a massive spruce bark beetle (Dendroctonus rufipennis) infestation which occurred in the 1940's, and although dense, the forest is primarily composed of relatively young trees.

Currently, the site is located at the upper limit of lodgepole pine, and only a few young individuals occur near the meadow. Other common species found at the site are Betula glandulosa (bog birch), Salix sp. (willow), Ribes coloradense (Colorado current), Rosa woodsii (wild rose), as well as many subalpine herbaceous taxa. Several taxa of Cyperaceae dominate the vegetation of the meadow proper. A complete list of identified taxa surrounding Dome Creek Meadow can be found in Appendix A.

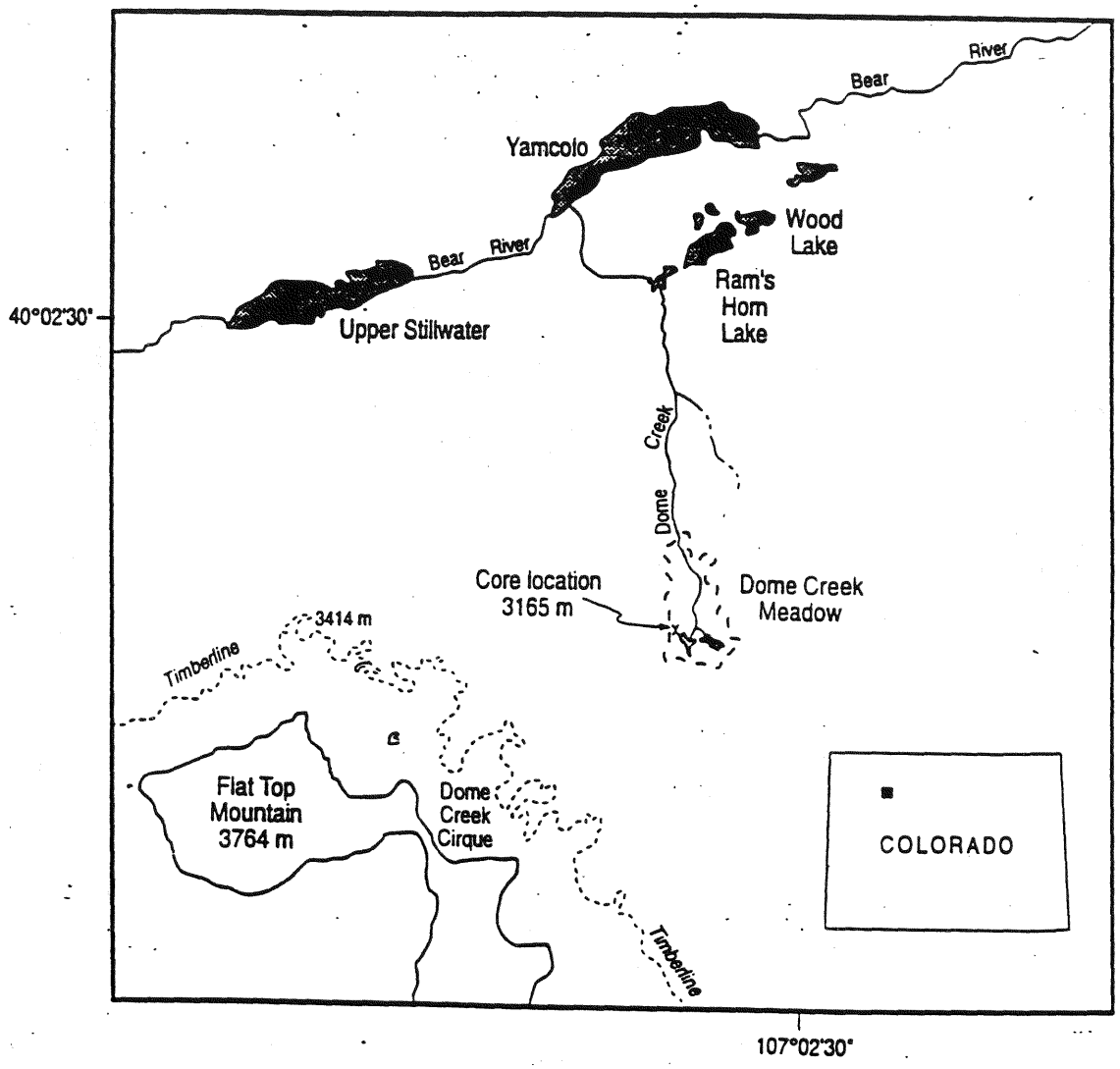


Figure 1: Location map of study area and surrounding region

Methods

A 5.85 m core was extracted from Dome Creek Meadow. Sampling of the first 40 cm of this core was accomplished with a 7.5 cm bucket auger at 10 cm intervals. Subsequent portions of the core were extracted using a modified Livingstone piston corer. The core was transported to the Laboratory of Paleoecology (LOP), were it was processed and sampled for pollen, plant macrofossils, and radiocarbon dates.

Pollen samples (1 cc) were taken at 20-cm intervals for the length of the core. A known concentration of exotic spores (Lycopodium) was added to each sample to monitor any degradation resulting from chemical processing and to estimate pollen concentration and influx data (Stockmarr, 1972). Samples were treated with 10% KOH, washed through 0.18 mm mesh screen, and treated with HCl and HF. The remaining samples received two minutes of acetolysis (Faegri and Iverson, 1989), were stained and suspended in glycerol. Samples high in clay content were sieved through a 0.008 mm nitex mesh to remove particles smaller than 8 microns (Cwynar et al., 1979).

Pollen identifications were made using the reference material housed at the Laboratory of Paleoecology, and to published keys (Erdtman, 1952; Kapp, 1969; Moore et al., 1991). Sample slides were examined by counting transects at 400x magnification to a 300-grain sum. Cyperaceae, Pediastrum, and Umbellifereae were counted outside the pollen sum and are reported as percentages outside the terrestrial pollen sum.

Plant macrofossil samples were taken at the same depths as pollen samples. These 5 cm long, half-core samples were allowed to dissagregate in water for approximately one week. They were then screened over two nested screens (.8 and .18 mm). Coarse fraction remains were sorted and counted under 10-40x magnification. Fine fraction samples were scanned for potential remains, but due to limited macrofossil content were not included in final macrofossil counts. Macrofossil identifications are based on the LOP reference collection. Conifer needle fragments were measured to the nearest mm, and are reported as total needle length by sample. Other macrofossils are reported as total specimens per 100 cc of sediment.

Results

Core Description:

The Dome Creek Meadow core consists of four distinct stratigraphic units. Medium sand with little organic sediment occurs from 5.85-5.65 m. Lake sediment occurs from 5.65 to 4.65 m. These sediments are predominantly banded, organic silty-clays. Some coarse organic sediments are found throughout this unit. Alluvial sediments occur from 4.65-3.62 m. These sediments are probably overbank deposits, with alternating bands of organic, peaty sands and medium to fine sands. Sedge peat occurs from 3.62 m to the surface. No obvious stratigraphic changes are apparent in the peat. A complete core description can be found in Appendix B.

Chronology:

Five radiocarbon dates were obtained on bulk organic sediments from Beta Analytic, Inc. Samples consisted of half-core segments 5 to 15 cm long. Samples were taken at the base of the core and at levels where significant shifts in pollen and macrofossil assemblages occurred. Results are presented in Table 1.

In addition, a protohistoric date of 120 yr BP was assigned for the uppermost decline in spruce based upon the observation of Sudworth (1900), who identified a spruce bark beetle outbreak within the area during the 1870's.

Table 1
Radiocarbon Dates

Beta #	Depth (cm)	Date(yr BP)
67902	245-259	4759 +/- 80
67903	357-362	7800 +/- 100
67904	452-462	10090 +/- 80
69029	547-562	10600 +/- 180
65351	562-582	9840 +/- 150

Beta-65351 represents a significant date reversal. This sample was the first dated. Later, when a date of 10,090 +/- 80 was returned stratigraphically above Beta-65351, the basal section of the core was resampled and dated at 10,600 +/-180 (Beta-69029). We believe that Beta-65351 included younger contaminated material. Sediment accumulation rates were calculated using the top four dates in Table 1. Figure 2 illustrates sediment accumulation rates through time.

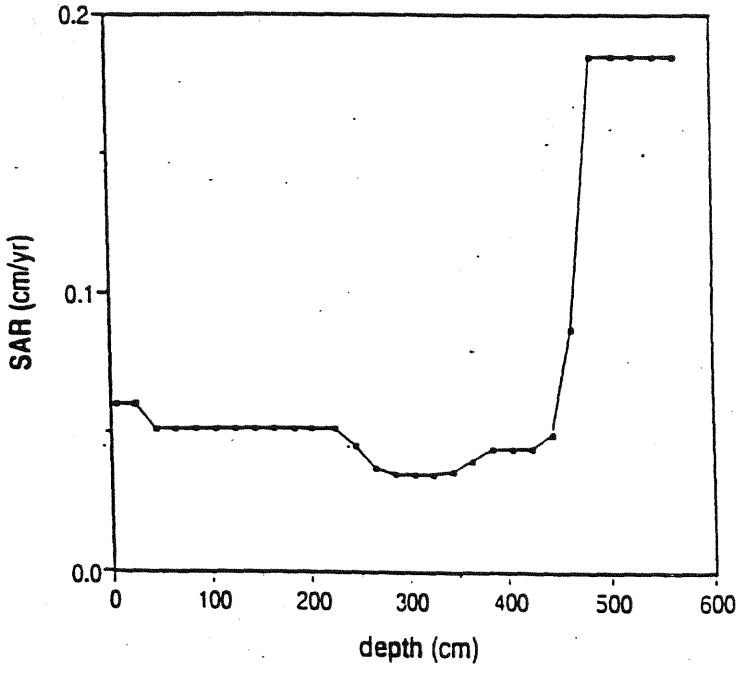


Figure 2: Sediment accumulation rates for Dome Creek Meadow Core #2

Significant changes in sediment accumulation rate (SAR) occur within the core. From the base of the core to 4.85 m, the SAR is rapid, approximately 0.185 cm/year. Between 4.65 and 4.45 m the SAR slows drastically, averaging ca. 0.044 cm/year until 365 cm. From 3.45 to 2.65 m the SAR is at it lowest point in the core, approximately 0.036 cm/year. From 2.45 m to 0.3 m the SAR increases again and remains consistent throughout this interval, approximately 0.054 cm/year. From .3 m to the top of the core the SAR increases slightly to 0.060 cm/year.

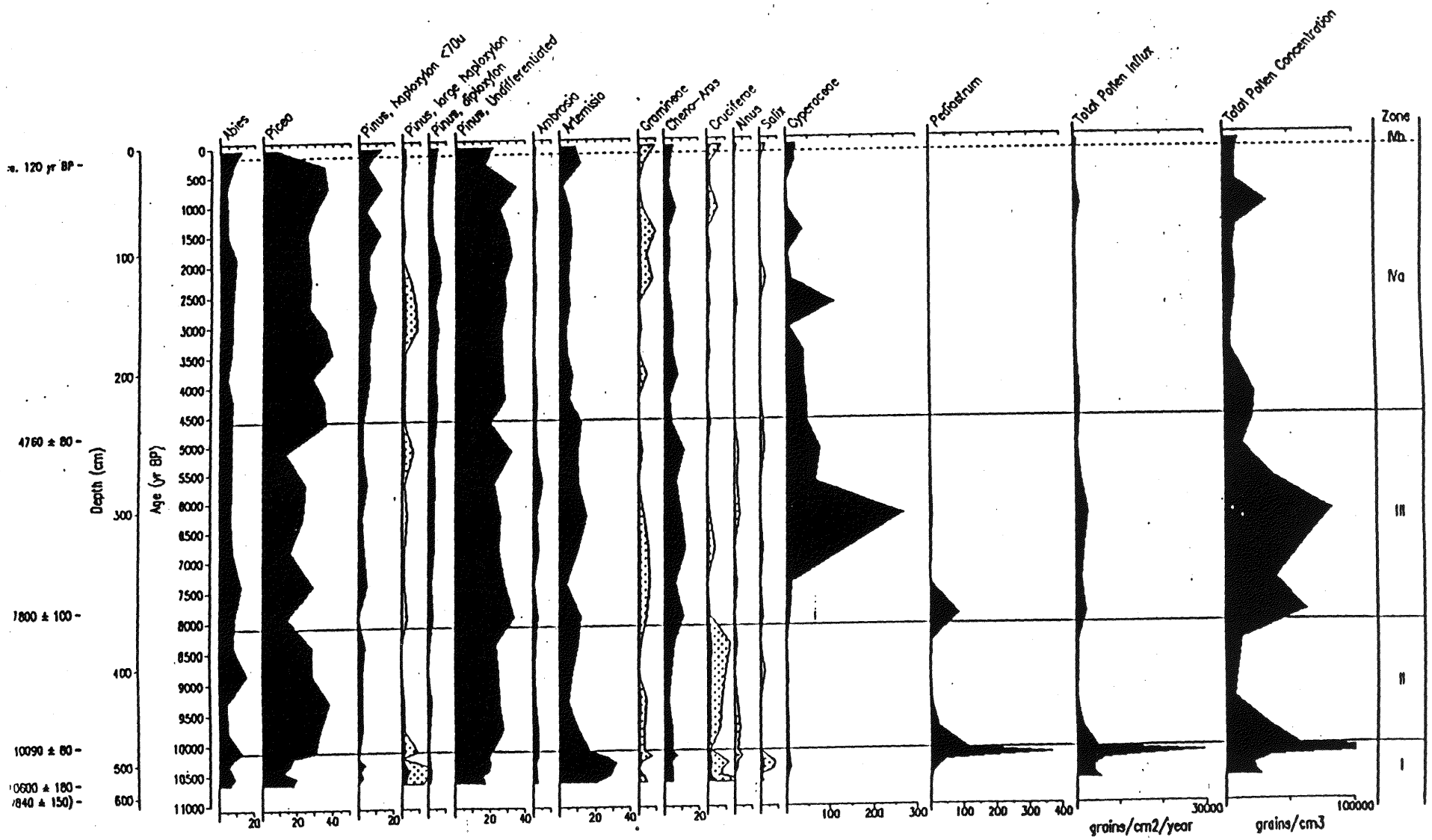
Pollen Data:

Thirty-three pollen taxa, and the fresh water algal colony, Pediastrum, were identified from twenty-nine pollen samples. Figure 3 illustrates the relative percentages of the most common taxa through time, as well as total pollen concentration (grains/cc) and pollen influx (grains/cm^2/yr). A complete list of identified taxa is located in Appendix C. Four zones were defined on the basis of pollen stratigraphy.

Zone I (10,600 to 10,120 yr BP)

Zone I is characterized by high percentages of Artemisia (to 32%), coupled with relatively low percentages of pinyon pine type (pinus, haploxylon <70u) (<5%), diploxylon pine (<5%), and undifferentiated pine (20%). Relative percentages of Picea are also low (<20%). Interestingly, large haploxylon pine (bristlecone or limber pine) shows its highest percentage (4%)

Selected Pollen Percentages from Dome Creek Meadow Core # 2



Silhoutte Exaggeration x 5

during this interval. Abies percentages (approx. 10%) are consistent with most other portions of the core . Cyperaceae percentages are low, while Pediastrum reaches its highest percentage in the core. Salix shows its highest percentages during this zone (<5%). Pollen concentration and influx both peak during this zone.

Zone II (10,120 to 8100 yr BP)

This zone is based primarily on the dramatic increase of Picea from Zone I percentages to a peak of 39%. Additionally, undifferentiated pine percentages increase to between 20 and 30%, while Artemisia percentages drop to as low as 5%. Abies reaches its highest percentages in the core during two separate peaks (14 and 17%). Pediastrum percentages drop dramatically, and eventually this taxa becomes absent from the assemblage during this interval. Cyperaceae percentages remain low.

Zone III (8100 to 4600 yr BP)

This zone is characterized by low (14%) and unstable Picea percentages associated with elevated undifferentiated pine percentages. Undifferentiated pine also peaks twice during this interval (35%, 33%). Abies percentages remain relatively high (12-13%) during the earliest portion of this zone, and then drop to between 7-8% for the remainder of the zone. The open ground taxa Ambrosia, and Cheno-Am also reach their highest percentages during this zone (approx. 6% and 12% respectively). Artemisia

percentages are relatively high and reach a second peak (16%). Pediastrum briefly reappears in this zone. Cyperaceae abruptly increases and peaks at its highest percentage of the core. With the exception of the peaks in Zone I, pollen concentration and influx are also at their highest and most consistent percentages for the core.

Zone IV (4600 yr BP to present)

Two subzones are defined for this zone. In zone IVa (4600 to 700 Yrs. yr BP), Picea peaks at 40% and remains relatively high (27-28%) until 700 yr BP when it peaks again at 38%. Cheno-Ams, Ambrosia, and Artemisia, all return to low percentages after peaks in zone III. After a brief drop, undifferentiated pine remains relatively stable at percentages consistent with the previous zone (25-30%) until, like Picea, it peaks again at 700 yr BP (35%). Other pine taxa, most notably pinyon type, show gradual but steady increases until the very uppermost portion of the core where they begin to fluctuate (ca. 1400 yr BP). Cyperaceae percentages are lower than zone III.

Subzone Ivb (ca. 120 yr BP to present) is characterized by slight increases in pine percentages after relatively significant declines, a drastic decrease in Picea pollen to a low of 8.4%, and a third minor peak in Cheno-Ams (5%) and Artemisia (12%) percentages. The large drop in spruce values is assumed to be registering the historic spruce bark beetle outbreaks. Abies attains a final peak (13%) and Cyperaceae shows slight increases

Discussion

Pollen, macrofossil, and stratigraphic data from Dome Creek Meadow core # 2 provide a record of paleoenvironmental change for the last 10,600 years. In general, pollen and macrofossil data are closely correlated. Changes in sediment stratigraphy, particularly for the non-peat sections of the core, also follow changes in pollen and macrofossil assemblages.

10,600 to 10,120 yr BP

This portion of the core is interpreted as representing a very early, post-glacial environment. The basal date of 10,600 years provides a minimum date for the glacial retreat associated with the Dome Creek recessional moraine that formed the meadow. Since the moraine was formed prior to 10,600 yr BP, the age of the moraine may be contemporaneous with the Younger Dryas, dated to ca. 11,000 yr BP. This date does not correlate well with the Holocene Front Range glacial chronology described earlier. The early Holocene Satanta peak advance is dated almost 1000 later, and the final Pinedale deglaciation is dated between 12,000-15,000 yr BP. This suggests that the timing of deglaciation in the Colorado Rockies may not have been synchronous from place to place. Alternatively, the basal date of the Satanta Peak deglaciation may be a somewhat younger minimum date. The possibility then exists that the Dome Creek Meadow moraine is in fact similar in age to the Satanta Peak moraines. In either case the new older date at Dome Creek suggests that southern Rocky Mountain Holocene glacial chronologies need refinement through

more accurate dating techniques, or that regional differences in glacial histories actually exist. Clearly the extent of glacial deposits in the BRC could provide significant data relative to this problem.

Macrofossils of spruce and fir indicate that by 10,500 yr BP both conifers had recolonized the area. Fall (1988, 1992) used pollen percentages to determine local presence. Pollen data are in agreement with percentages for those taxa at or above percentages high enough to indicate the trees' presence. High percentages of Cheno-Ams, Artemisia, and Ambrosia indicate that there was not a closed forest at the site and significant areas of open ground existed. The surrounding area was either near the upper limit of treeline, perhaps in the krumholz zone, or trees were literally just recolonizing the area after the Pinedale retreat. The pollen data indicates that by 10,120 yr BP, both spruce and fir had become much more common, while the open ground taxa had started to decline indicating a closing of the spruce-fir forest. Cool-moist conditions appear to have replaced the cool-dry conditions of the earliest Holocene.

Sediment stratigraphy, low Cyperaceae percentages, and the occurrence of the aquatic taxa, Pediastrum and Potamogeton, indicate that the moraine had dammed some portion of the outwash associated with the retreating glacier and formed a pond.

10,120 to 8100 yr BP

Pollen and macrofossils indicate that this period is

characterized by continued cool-moist conditions supporting a closed spruce-fir forest around the site. The sediment record indicates that the lake that had formed earlier had silted up relatively rapidly, and was essentially gone by ca. 10,000 yr BP. Sediments deposited at this time are banded (alternating sands with organic, peaty-sands), coarser and more organic with the highest macrofossil abundances of the core. This coincidence indicates that either trees were more abundant at the site or that different taphonomic processes affected macrofossil deposition. Pollen data suggest that the former is the case with percentages of both spruce and fir increasing and reaching relatively high percentages *before* the lake-alluvial sediment transition. Periodic ponding events (beaver ponds?) may have occurred as indicated by the continued presence of Pediastrum and Potamogeton. All evidence indicates that the area had become a wet meadow or marsh, braided with small streams, surrounded by a forest community similar to that seen today. This environment persisted until approximately 8100 yr BP

8100 to 4600 yr BP

This period represents one of major change to the local forest community. While fir pollen percentages remain relatively consistent throughout this interval, spruce pollen fluctuates dramatically, reaching some of the lowest percentages of the core. Pine pollen percentages peak twice (35 and 33%) and are consistently higher than the previous interval. This increase coupled with low spruce percentages agrees with the

interpretations from other Colorado sites which suggest an elevated upper treeline. On the other hand, the increase in open ground taxa suggests, for whatever reason, an opening of the forest community surrounding the site, and not simply an upward shift in vegetation zones in response to elevated temperatures.

Sedge peat formation begins at ca. 7900 yr BP. High Cyperaceae percentages occurring by ca. 7000 yr BP suggest increased effective precipitation. Conversely, the lower sediment accumulation rate argues for lower effective precipitation. This zone exhibits the lowest sedimentation rates of the core. This is counterintuitive to what would be expected if increased moisture had stimulated an increase in the sedge population. We suggest that the interval from 3.25 m and 2.85 exhibits an even lower SAR than the entire zone III, effectively concentrating sedge pollen (and macrofossils) as indicated by the high pollen concentration rates for this interval. Total sedge pollen production probably stayed relatively stable, while overall growth and production of sedge peat, was reduced. The sedge spike seen during this interval then is explained by a simple increase in sedge pollen concentration.

If effective precipitation was reduced during the middle Holocene, as the stratigraphic record indicates, the changes in the relative percentage of pine taxa could represent the retreat of lower timberline upwards in elevation, with pine becoming more important at the site. Since upper timberline is not precipitation dependent, the reduction in spruce values probably

represent increased temperatures reflected by spruce's expansion upwards in elevation. It is also possible that the reductions in spruce values are registering spruce's response to disease or insect predation. There is ample historic evidence that spruce populations on the White River Plateau have been significantly influenced by bark beetle infestations at least twice during the last 100-120 years. The most recent infestation in the 1940's caused a near forest-wide die-off of mature spruce (Schmid and Frye, 1977). These events are captured in the upper 15 cm of the core. Spruce percentages during the middle Holocene drop to percentages very near the levels correlated with these events. Unfortunately, the peat sediments at Dome Creek Meadow do not contain abundant macrofossils, including insects. Therefore it is nearly impossible to determine the possible role insects might have had. Other cores, particularly from lakes, would stand a much better chance of containing insect fossils and the data necessary to explore this possibility.

By ca. 4800 yr BP spruce begins to return to higher percentages and percentages of more open ground taxa drop. Climate or disturbance conditions that caused events seen in the middle Holocene sections of the core changed so that a dense spruce-fir forest once again formed around the site.

4600 yr BP to Present

This interval represents a mostly stable period dominated by relatively cool moist conditions as indicated by the dominance of spruce and fir at Dome Creek Meadow. Increased peat accumulation

rates during this interval suggest elevated groundwater level, probably due to greater effective precipitation. Pinyon pine type pollen increases during this interval and probably reflects the migration of pinyon (probably Pinus edulis) northwards in the intermountain area west of the site (Betancourt, 1984; Van Devender, 1986; Wells, 1986). After a brief reduction in spruce percentages ca. 2800 yr BP both spruce and pine reach final peaks at ca. 700-300 yr BP.

The period from ca. 120 yr BP to the present (Zone IVb), represents a second disruption in the forest community similar to that seen during the middle Holocene. Artemisia in particular shows a relatively large increase, and spruce eventually drops to the lowest percentages of the core. As mentioned earlier, this reduction in spruce pollen is probably reflecting the major insect infestations of the late 18th and middle 20th centuries.

The large spruce peak that occurs just before the subzone IVb boundary, corresponds to the timing of the Little Ice Age, dated ca. 150-550. This peak then probably reflects spruce's, and timberline's, retreat downward in elevation in response to cooler temperatures. The reduction of pine values, while spruce percentages stay relatively high, could also reflect pine's retreat to lower elevations. This left spruce more dominant at the site until the spruce bark beetle infestations caused spruce to decline also (as represented by the Zone IVb boundary). The eventual final increase of pine percentages represent pine's increased importance at the site in response to potential warming

after the Little Ice Age. Also, the dramatic reduction of spruce due to infestation, undoubtedly fascilitated pine's importance at the site.

Summary

The data from Dome Creek Meadow provides a sensitive record of environmental change over the last 10,600 years, and indicates that the vegetation community of the BRC has reacted dynamically to changing environmental factors. During the Pleistocene the BRC was heavily glaciated as evidenced by the extensive glacial deposits found nearly everywhere in the area. Colorado glacial chronologies suggest that much of the southern Rocky Mountains were deglaciated between 12,000 and 15,000 yr BP. This may have been the case for the BRC, although the basal date from the Dome Creek core suggest that protected areas, particularly northeast facing cirques and associated drainages, still retained glacial ice as late as ca. 11,000 yr BP. This date which represents a minimum date for the retreat of the Dome Creek lobe is extremely close to the age of the Younger Dryas event, suggesting the glacial chronology of the White River Plateau needs further study. If this is a Younger Dryas event it suggests a more global climatic preterbation, not limited to the North Atlantic. Additional work is also suggested because of the discrepancies in the timing of deglaciation in northern Colorado. A concerted effort to accurately map and date glacial features within and surrounding the BRC will be important in refining this chronology.

The early Holocene in the BRC witnessed a drastic change from a cool, dry, open periglacial environment, to a cool, moist forested environment. Spruce and fir rapidly recolonized the

area after deglaciation suggesting that glacial populations of these taxa existed not far from the site. These cool, moist conditions changed drastically ca. 8100 yr BP as temperature appears to have increased. This increased temperature caused 1) upper treeline to advance in elevation, 2) lower treeline to retreat upwards in elevation, 3) increased stress leading to reduced resistance to disease and infestation for spruce (and potentially other forest taxa), 4) reduced effective precipitation, or 5) some combination of all four. More data are needed to clarify these problems. Whatever the reasons, conditions changed so that spruce was a much less important member of the surrounding community, and the forest appears to have become more open. By 4600 yr BP conditions ameliorated and a closed spruce-fir forest once again surrounded the site. The latest Holocene is characterized by major shifts in the forest community, most notably reduction in both spruce and pine after peaks at ca. 700 yr BP. This change corresponds well with the timing of the Little Ice Age.

For unknown reasons, the last 120 years witnessed periodic outbreaks of spruce bark beetle which significantly altered the structure of the forest community. These outbreaks began after a significant shift in climate (the end of the Little Ice Age), and suggest the possibility of a link between climate shifts and large scale insect infestation. The unique historic record of infestation seen in the BRC and the White River Plateau, suggest that the prehistoric record might also be unique and could

potentially address this problem.

Overall the record from Dome Creek Meadow is exciting since it presents the possibility of several new interpretations relative to Colorado paleoecology. Besides providing the first paleoenvironmental data for the White River Plateau, the Dome Creek core provides new insights into the potential role of other factors in environmental change, besides changes in precipitation and temperature regimes. Although the data are preliminary, the basal date on the core also suggests the need for refinement of glacial chronologies as well. The almost unlimited number of paleoecological sites (lakes, ponds, bogs and meadows) in and around the BRC indicate that the Flat Tops are an untapped wealth of paleoecological information and many of these unresolved questions could be addressed with further study in this area.

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References Cited

Andrews, J.T., Carrara, P.E., King, F.B., Stuckenrath, R. 1975. Holocene environmental changes in the alpine zone, northern San Juan Mountains, Colorado: evidence from bog stratigraphy and palynology. *Quaternary Research* 5:173-197.

Atwood, W.W., and Mather, K.F. 1932. Physiography and Quaternary geology of the San Juan Mountains, Colorado. USGS Professional Paper 166.

Benedict, J.B. 1967. Recent glacial history of an alpine area in the Colorado Front Range, USA I: establishing a lichen growth curve. *Journal of Glaciology* 6:817-832.

1973. Chronology of cirque glaciation, Colorado Front Range. *Quaternary Research* 3:584-599.

Betancourt, J.L. 1984. Late Quaternary plant zonation and climate in southeastern Utah. *Great Basin Naturalist* 44:1-35.

Birkeland, P.W., and Miller, C.D. 1973. Status and correlation of Quaternary stratigraphic units in the western coterminous United States. *Quaternary Research* 1:208-227.

Birkeland, P.W., and Shroba, R.R. 1974. The status of the concept of Quaternary soil-forming intervals in the Western United States. In W.C. Mahaney, ed., "Quaternary Environments: Proceedings of a Symposium", pp 241-276. Geographical Monographs, York University-Atkinson College, Toronto.

Birkeland, P.W., Crandell, D.R. and Richmond, G.M. 1971. Recent interpretation of the type Temple Lake moraine, and other Neoglacial deposits, southern Wind River Mountains, Wyoming. *Geological Society of America, Rocky Mountain Section, 26th Annual Meeting, Program with Abstracts* 5:465-466.

Borchert, J.R. 1950. The Climate of the central North American grasslands. *Annals of the Association of American Geographers* 40(1)1-39.

Bryson, R.A. 1980. Ancient climes on the Great Plains. *Natural History* 89(6):65-73.

Burke, R.M., and Birkeland, P.W. 1983. Holocene glaciation in the mountain ranges of the western United States. In Wright, H.E., Jr., ed., "Late Quaternary Environments of the United States, Vol 2: The Holocene", pp 3-11. University of Minnesota Press, Minneapolis.

Carrara, P.E., and Andrews, J.T. 1973. Holocene deposits in the alpine of the San Juan Mountains, SW Colorado. *Geological Society of America, Rocky Mountain Section, 26th Annual Meeting, Program with Abstracts* 5:469-470.

Carrara, P.E., Mode, W.N., Rubin, M., and Robinson, S.W. 1984. Deglaciation and post glacial timberline in the San Juan Mountains, Colorado. *Quaternary Research* 5:42-55.

COHMAP. 1988. Climatic changes of the last 18,000 years: Observations and model simulation. *Science* 241:1043-1052.

Cwynar, L.C., Burden, E., and McAndrews, J.H. 1979. An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. *Canadian Journal of Earth Sciences* 16:1115-1120.

Ecological Science and Snow Survey. 1989. "Temperature, Precipitation, Frost, and Growth Data from Selected Stations". Soil Conservation Service, Lakewood.

Davis, P.T., and Waterman, S.E. 1979. New radiocarbon ages for type Triple Lakes moraines, Arapahoe Cirque, Colorado Front Range. *Geological Society of America, Abstracts with Programs* 11:270.

Davis, P.T. and Zielinski, G.A. 1988. Suggestion for selection of type localities for alpine deposits of Holocene and Pleistocene age. *American Quaternary Association, Programs and Abstracts of the tenth biennial meeting*, pp 120-121.

Fall, P.L. 1988. "Vegetation Dynamics in the Southern Rocky Mountains: Late Pleistocene and Holocene Timberline Fluctuations". Ph.D. Dissertation, University of Arizona, Tucson.

1992. Pollen accumulation in the montane region of Colorado, USA: a comparison of moss polsters, atmospheric traps, and natural basins. *Review of Paleobotany and Palynology* 72:169-197.

Erdtman, G. 1952. "Pollen Morphology and Plant Taxonomy". Almquist and Wiksell, Stockholm.

Faegri, K., and Iverson, J. 1989. "Textbook of Pollen Analysis", 4th edition. John Wiley and Sons, New York.

Fenneman, N.M. 1931. "The Physiography of the Western United States". McGraw-Hill Book Co., New York.

Harrington, J.A., Jr., and J.R. Harman. 1991. Climate and vegetation in central North America: Natural patterns and human alterations. *Great Plains Quarterly* 11:103-112.

Ives, R.L. 1938. Glaciation at the headwaters of the Laramie, Cache La Poudre, and Colorado Rivers, Colorado. *GSA Bulletin* 49:1888-1889.

Kapp, R.O. 1969. "How to Know Pollen and Spores". WM. C. Brown Company, Dubuque.

Legg, T.E., and Baker, R.G. 1980. Palynology of Pinedale sediments, Devlins Park, Boulder County, Colorado. *Arctic and Alpine Research* 12:319-333.

Leonard, E.M. 1979. Topography and glaciation in the San Juan Mountains and Front Range, Colorado. *Geological Society of America, Abstracts with Programs* 11:118-122.

Madole, R.F. 1969. Pinedale and Bull Lake glaciation in the upper St. Vrain drainage basin, Boulder County, Colorado. *Arctic and Alpine Research* 1:279-287.

1980. Time of Pinedale deglaciation in north-central Colorado: Further considerations. *Geology* 8:118-122.

1986. Lake Devlin and Pinedale glacial history, Front Range, Colorado. *Quaternary Research* 25:43-54.

Mahaney, W.C. 1972. Audobon: New names for Colorado Front Range Neoglacial deposits formerly called "Arikaree". *Arctic and Alpine Research* 4:355-357.

Maher, L.J. 1961. "Pollen Analysis and Post-Glacial Vegetation History of the Animas Valley". Ph.D. dissertation, University of Minnesota.

1963. Pollen analysis of surface materials from the southern San Juan Mountains, Colorado. *GSA Bulletin* 74:1485-1504.

Markgraf, V., and Scott, L. 1981. Lower timberline in central Colorado during the last 15,000 years. *Geology* 9:231-234.

Marr, J.W. 1961. Ecosystems of the Front Range, Colorado. *University of Colorado Series in Biology*, No. 8.

Miller, A.E. 1977. Descriptive text for landform and geologic hazards maps, Routt National Forest.

Moore, P.D., Webb, J.A., and Collinson, M.E. 1991. "Pollen Analysis", Second Edition. Blackwell Scientific Publications, London.

Moss, J.H. 1951. late glacial advances in the southern Wind River Mountains, Wyoming. *American Journal of Science* 249:865-883.

Nelson, A.R., Millington, A.C., Andrews, J.T., and Nichols, H. 1979. Radiocarbon dated upper Pleistocene glacial sequence, Fraser Valley, Colorado Front Range. *Geology* 7:410-414.

Pierce, K.L. 1979. History of dynamics of glaciation in the northern Yellowstone National Park area. USGS Professional Paper 729-F.

Pierce, K.L., Obradovich, J.D., and Friedman, I. 1976. Obsidian hydration dating and correlation of Bull Lake and Pinedale glaciations near West Yellowstone, Montana. *GSA Bulletin* 87:703-710.

Petersen, K.L. and Mehringer, P.J. 1976. Postglacial timberline fluctuations, La Plata Mountains, southwestern Colorado. *Arctic and Alpine Research* 8:275-288.

Rameley, F. 1927. "Colorado Plant Life". University of Colorado Press, Boulder.

Ray, L.L. 1939. Subdivision of the last glacial stage in the southern Rocky Mountains (Abstract). *GSA Bulletin* 51:2006-2007.

1940. Glacial chronology of the southern Rocky Mountains. *GSA Bulletin* 51:1851-1918.

Reider, R.G. 1971. "A geomorphological and pedological interpretation of the White River Plateau, Colorado". Ph.D. dissertation, University of Nebraska, Lincoln.

Richmond, G.M. 1954. Modifications of the glacial chronology of the San Juan Mountains, Colorado. *Science* 119:614-615.

1957. Three pre-Wisconsin glacial stages in the Rocky Mountain region. *GSA Bulletin* 68:239-262.

1960. Glaciation on the east slope of Rocky Mountain National Park, Colorado. *GSA Bulletin* 71:1371-1382.

1965. Glaciation of the Rocky Mountains. In Wright, H.E., Jr., and Frey, D.G. eds., "The Quaternary of the United States", pp 217-230. Princeton University Press, Princeton.

Schmid, J.M., and Frye, R.H. 1977. "Spruce beetle in the Rockies". USDA Forest Service Technical Report RM-49.

Short, S.K. 1985. Palynology of Holocene sediments, Colorado Front Range: vegetation and treeline changes in the subalpine forest. *AASP Contribution Series* 16:7-30.

Stockmarr, J. 1972. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13:615-621.

Sudworth, G.B. 1900. "White River timberland reserve", in Twentieth Annual Report, 1898-1899, USGS, Part V, Forest Reserves.

Van Devender, T.R. 1986. Late Quaternary history of pinyon-juniper-oak woodlands dominated by Pinus remota and Pinus edulis. In Everett, R.L., compiler, "Proceedings: Pinyon-Juniper Conference", pp 99-103. USDA, Forest Service, General Technical Report INT-215.

Wells, P.V. 1986. Systematics and distribution of pinyons in the late Quaternary. In Everett, R.L., compiler, "Proceedings: Pinyon-Juniper Conference", pp 104-108. USDA, Forest Service, General Technical Report INT-215.

White, S.E. 1971. Rock glacier studies in the Colorado Front Range. *Arctic and Alpine Research* 3:43-64.

Zielinski, G.A., and Davis, P.T. 1987. Late Pleistocene age of type Temple Lake moraine, Wind River Range, Wyoming, U.S.A. *Geographie physique et Quaternaire* 41:397-401.

Appendix A:
Modern Plant Species Occurring
at
Dome Creek Meadow

Plant Taxa from Dome Creek Meadow	Eric Feiler and Peter Koehler
Scientific Name	Common Name
Abies lasioscarpa	Subalpine fir
Achillea lanulosa	Yarrow
Aconitum columbianum	Monkshood
Antennaria sp.	Pussytoes
Aquilegia caerulea	Colorado columbine
Arctostaphylos uva-ursi	Kinnikinnik
Arnica cordifolia	Heart leaved arnica
Aster porteri	Porters aster
Astragalus sp.	Locoweed
Artemisia sp (herbaceuos)	Sage
Betula glandulosa	Bog birch
Caltha leptosepala	Marsh marigold
Carex spp.	Sedge
Castilleja linariefolia	Wyoming paintbrush
Castilleja miniata	Scarlet paintbrush
Cerastium arvense	Mouse-eared chickweed
Cirsium sp.	Thistle
Dugaldia hoopesii	Orange sneezeweed
Equisetum arvense	Field horsetail
Eriogonum lonchophyllum	False buckwheat
Frageria ovalis	Stawberry
Frasera speciosa	Green gentian
Geranium richardsonii	White geranium
Heracleum sphondylium ssp. montanum	Cow parsnip
Ipomopsis agregata	Trumpet gilia
Juniperus communis	Common juniper
Lathyrus leucanthus	White-flowered pea vine
Limnorchis dilatata ssp. albiflora	White bog orchid
Lonicera involucrata	Bush honeysuckle
Lupinus argenteus	Common Lupine
Luzula sp.	Wood rush
Mertensia sp.	Bluebells
Nasturtium officianale	Water cress
Pedicularis groenlandica	Elephantella
Pedicularis parryi	Lousewort
Penstemon whippleanus	Beard tongue
Phacelia sericea	Purple fringe
Picea engelmannii	Engelmann spruce
Pinus contorta var. latifolia	Lodgepole Pine
Potentilla sp.	Cinquefoil
Pseudocymopterus montanus	Yellow mountain parsley
Ranunculus alismaefolius var. montanus	Plantain-leaf buttercup
Ribes coloradense	Colorado current
Rorripa curvipes var. alpina	Cress
Rosa woodsii	Wild rose
Rumex sp.	Dock
Salix sp.	Willow

Plant Taxa from Dome Creek Meadow, con't	Eric Feiler and Peter Koehler
Scientific Name	Common Name
Sambucus racemosa ssp. pubens	Red berried elder
Senecio sp.	Butterweed
Senecio triangularis	Butterweed
Solidago multiradiata	Goldenrod
Thalictrum sp.	Meadow-rue
Thlaspi montanum	Wild candytuft
Urtica dioica ssp. gracilis	Stinging nettle
Veratrum californicum	Skunk cabage
Viola adunca	Mountan blue violet

Appendix B:
Core Description

Core Description
Dome Creek Meadow Core # 2

Drive	Depth(cm)	Sediment Description	Munsell Color Code
Auger 1	0-10	sedge peat, silty clays, fine to coarse organics	5YR 2.5/1
Auger 2	10-20	same	same
Auger 3	20-30	same	same
Auger 4	30-40	same	same
1	35-65	same	same
2	65-67	same	same
	67-73	same	5YR 3/1
	73-90	same	5YR 2.5/1
3	90-107	same	same
4	107-141	same	same
5	141-204	same	same
6	204-297	same	same
7	297-301	same	same
	301-311	same	5YR 3/1
	311-318	dark organic banding	
	318-320	sedge peat, silty clays, fine to coarse organics	5YR 2.5/1
	320-325	dark organic banding	
	325-330	sedge peat, silty clays, fine to coarse organics	5YR 2.5/1
	330-333	dark organic banding	
	333-343	sedge peat, silty clays, fine to coarse organics	5YR 2.5/1
8	343-362	same	same
	362-370	clayey peat, fine sand, fine to coarse organics (transition to alluvial-organic sediments)	same
	370-382	fine to medium sands with silt and clay	5YR 4/3
	382-387	fine to medium sand with silt, fine to coarse organics	5YR 2.5/1
	387-388	fine to medium sands with silt and clay	5YR 4/3
9	388-390	fine to medium sand with silt, fine to coarse organics (peaty sand)	7.5YR 4/2
	390-392	dark organic banding	
	392-393	fine to medium sand with silt, fine to coarse organics (peaty sand)	7.5YR 4/2
	393-394	dark organic banding	
	394-397	fine to medium sand with silt, fine to coarse organics (peaty sand)	7.5YR 4/2
	397-399	dark organic banding	
10	399-421	fine to medium silty sand, fine	7.5YR 4/2

organics. Subtle organic banding at 402-402.5, 403.5-404, 405.5-406,

core description continued:

Drive	Depth(cm)	Sediment Description	Munsell Color Code
10		408-408.5, 413-415.5	
	421-427	fine to medium silty sand, fine organics. Coarse sand lens at 423.5-424	5YR 2.5/1
	427-435	organic silt, fine to medium organics	5YR 2.5/1
11	435-445	organic silt, fine to medium organics	5YR 2.5/1
	445-457	silty clay, fine organics (transition to lake sediments)	7.5YR 4/2
	457-461	silty clay, dark organic banding	
	461-464	silty clay, fine organics	7.5YR 4/2
	464-465	silty clay, dark organic banding	
	465-468	silty clay, fine organics	7.5YR 3/2
12	468-493	silty clay, fine organics	10YR 3/2
	493-496	silty clay, dark organic banding	
	496-499	silty clay, fine organics	10YR 3/2
13	499-503	silty clay, fine organics, silty sand (possible contaminate-slump)	7.5YR 4/2
	503-533	silty clay, fine organics	10YR 4/2
14	533-547	silty clay, fine organics	10YR 4/2
	547-550	silty clay, dark organic banding	
	550-553	medium sand lens	
	553-555	silty clay, fine organics	10YR 4/2
	555-557	medium sand lens	
	557-560	silty clay, fine organics	10YR 4/2
	560-561	silty clay, dark organic banding	
	561-567	silty clay, fine organics	10YR 4/2
15	567-572	silty clay, fine organics	10YR 4.5/2
	572-574	fine to medium sands	
	574-575	silty clay, fine organics	10YR 4.5/2
	575-576	fine to medium sands	
	576-577	silty clay, fine organics	10YR 4.5/2
	577-585	fine to medium sands	

Appendix C:
Pollen data

Calculated Pollen Percentages For Dome Creek Meadow Core # 2

Depth	5.0	25.0	45.0	65.0	85.0	105.0	125.0	145.0	165.0	185.0
Calculated age	40.0	315.8	707.3	1098.9	1490.5	1882.0	2273.6	2665.1	3056.7	3448.3
Total Pollen Influx	673.4	544.9	489.0	1744.1	523.8	356.0	474.2	442.9	302.4	253.6
Total Concentration	11234.0	9090.2	9574.5	34146.3	10254.4	6969.4	9284.3	8671.7	5921.1	4965.6
Tracers	295.0	357.0	282.0	82.0	370.0	408.0	328.0	662.0	486.0	767.0
Deteriorated Pollen	4.7	4.5	1.6	8.3	2.3	3.0	3.6	2.5	0.3	2.3
Unknown Pollen	0.9	2.2	0.0	2.8	0.3	0.0	0.0	0.0	0.0	0.0
Abies	12.8	7.7	4.2	4.8	5.2	10.0	9.2	7.9	7.9	7.3
Picea	8.4	35.3	37.6	30.2	26.1	26.9	28.2	26.8	36.2	40.1
Pinyon Pine Type	12.8	5.1	13.5	4.6	12.7	6.3	5.9	9.8	6.6	6.3
Large Haploxylon	0.3	0.3	0.0	0.0	0.3	0.0	1.0	1.6	1.6	0.3
Diploxylon	5.3	3.8	2.3	2.0	2.6	6.3	7.2	3.5	5.9	4.0
Undifferentiated pine	21.8	17.3	35.0	25.4	30.4	32.6	28.2	29.3	26.8	27.2
Cupressaceae	2.5	1.0	0.0	1.4	1.6	0.3	1.3	2.5	0.7	0.0
Quercus	3.4	0.6	0.3	0.0	0.7	0.3	0.3	0.3	1.0	0.3
Ceanothus	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0
Cercocarpus	4.7	1.3	0.0	0.9	2.0	0.0	1.3	1.9	0.3	2.0
Rhamnus	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Ephedra	0.3	0.3	0.6	0.6	0.7	0.0	0.3	0.0	0.3	0.0
Rosaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Sarcobatus	1.2	0.0	0.0	0.6	0.3	0.7	1.3	0.0	0.3	0.3
Ambrosia	0.9	0.3	0.6	2.0	0.7	0.7	1.3	1.3	0.3	0.3
Artemisia	8.4	11.9	1.3	5.7	7.2	5.6	4.6	5.7	3.9	4.3
Cirsium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Liguliflorae	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Compositae	2.2	2.2	0.0	1.1	1.6	0.7	1.6	1.3	0.3	0.3
Gramineae	1.9	0.6	0.0	0.6	2.0	1.0	1.6	0.0	0.3	0.0
Cheno-Ams	5.3	3.5	2.6	6.8	2.9	3.7	2.3	4.1	5.6	4.6
Cruciferae	1.6	0.3	0.3	1.1	0.0	0.3	0.0	0.3	0.0	0.3
Eriogonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ranunculaceae	0.0	0.3	0.0	0.3	0.0	0.7	0.0	0.0	0.7	0.0
Leguminosae	0.0	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Labiatae	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thalictrum	0.0	0.6	0.0	0.3	0.3	0.7	0.3	0.9	0.0	0.0
Euphorbiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Betula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix	0.6	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
Cyperaceae	21.8	20.2	0.0	3.7	40.5	5.3	12.1	112.3	6.3	41.1
Polygonum-Type	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Typha latifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Umbelliferae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pediastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pollen Sum	321.0	312.0	311.0	351.0	306.0	301.0	305.0	317.0	304.0	302.0

Calculated Pollen Percentages For Dome Creek Meadow Core # 2

Depth	205.0	225.0	245.0	265.0	285.0	305.0	325.0	345.0	365.0	385.0
Calculated age	3839.8	4231.4	4623.0	5129.3	5697.6	6265.8	6834.0	7402.2	7937.4	8395.4
Total Pollen Influx	731.3	1183.2	972.1	513.9	1340.0	2921.7	2143.8	1420.7	2530.0	565.1
Total Concentration	14318.1	23165.0	21822.8	13805.8	38071.4	83009.7	60906.6	39189.9	62816.7	12940.3
Tracers	266.0	173.0	183.0	351.0	120.0	122.0	109.0	79.0	85.0	214.0
Deteriorated Pollen	1.7	1.9	1.3	4.8	2.2	1.0	2.6	1.3	3.2	5.1
Unknown Pollen	0.3	0.0	0.6	0.0	1.0	0.3	0.9	0.0	0.3	0.0
Abies	5.0	8.5	8.0	7.9	7.9	7.4	8.2	13.3	9.6	8.8
Picea	29.5	35.8	37.0	14.0	25.4	23.6	16.8	29.7	14.7	28.9
Pinyon Pine Type	7.0	5.0	2.9	3.1	5.4	2.3	4.1	5.7	0.3	4.4
Large Haploxylon	0.3	0.3	0.3	1.3	0.3	0.6	0.3	0.3	0.6	0.0
Diploxylon	4.3	5.3	4.5	3.1	4.1	3.9	3.5	2.0	2.9	1.1
Undifferentiated pine	27.8	28.9	20.6	32.8	22.9	26.5	25.9	29.3	34.6	23.8
Cupressaceae	0.0	0.0	0.3	0.9	1.0	0.3	1.2	1.0	0.6	0.4
Quercus	1.3	0.3	0.3	0.9	0.6	0.3	0.6	0.7	0.3	1.5
Ceanothus	0.0	0.0	0.3	0.4	0.0	0.0	0.3	1.0	0.0	0.0
Cercocarpus	3.0	1.9	2.6	3.9	2.5	2.6	3.5	0.7	2.2	0.0
Rhamnus	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Ephedra	0.0	0.0	0.3	0.0	0.0	0.6	0.0	0.3	0.0	0.4
Rosaceae	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Sarcobatus	0.0	0.0	0.6	0.9	0.0	0.3	1.5	0.7	0.0	0.4
Ambrosia	1.7	2.2	1.6	2.2	5.7	1.9	3.5	0.7	3.2	1.8
Artemisia	7.6	5.3	12.5	10.5	10.8	15.9	10.9	4.0	12.5	10.6
Cirsium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Compositae	1.3	0.3	1.3	1.3	1.6	0.6	0.9	0.3	1.6	1.8
Gramineae	1.0	0.0	0.0	0.4	0.0	0.6	1.2	1.3	1.0	0.4
Cheno-Ams	8.3	3.5	4.5	11.4	7.3	10.4	12.4	6.7	11.5	6.2
Cruciferae	0.0	0.0	0.3	0.0	0.0	0.3	0.9	0.0	0.3	2.6
Eriogonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Ranunculaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leguminosae	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0
Labiatae	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Thalictrum	0.0	0.3	0.0	0.0	0.0	0.3	0.6	0.3	0.0	0.4
Euphorbiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Alnus	0.0	0.0	0.0	0.4	0.3	0.6	0.0	0.3	0.0	0.4
Betula	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Salix	0.0	0.0	0.3	0.4	0.0	0.0	0.3	0.0	0.3	0.0
Cyperaceae	41.1	47.8	47.6	78.6	67.6	270.9	144.4	14.0	9.6	0.0
Polygonum-Type	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Typha latifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Umbelliferae	0.0	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Pediastrum	0.0	0.0	0.0	0.0	0.6	3.6	1.2	0.0	87.8	2.2
Pollen Sum	302.0	318.0	311.0	229.0	315.0	309.0	340.0	300.0	312.0	273.0

Calculated Pollen Percentages For Dome Creek Meadow Core # 2

Depth	405.0	425.0	445.0	465.0	485.0	505.0	525.0	545.0	565.0
Calculated age	8853.4	9311.4	9769.4	10122.2	10229.6	10336.9	10444.3	10551.7	10659.1
Total Pollen influx	437.8	316.1	1589.6	4964.3	29434.6	6476.5	4015.1	4159.7	5098.1
Total Concentration	10025.6	7239.5	32221.2	57111.1	158016.9	34768.4	21554.9	22331.1	27368.8
Tracers	282.0	391.0	110.0	103.0	81.0	123.0	176.0	132.0	103.0
Deteriorated Pollen	3.7	4.2	2.4	1.3	4.4	4.0	3.2	2.4	11.5
Unknown Pollen	1.0	1.6	0.7	0.6	0.9	0.7	2.5	2.8	3.1
Abies	16.8	5.2	5.5	13.8	9.2	6.0	7.6	9.5	6.8
Picea	29.3	39.0	33.7	30.7	18.4	16.4	12.7	19.6	18.3
Pinyon Pine Type	2.6	2.9	2.7	0.6	0.0	4.4	1.3	3.1	0.3
Large Haploxylon	0.0	0.3	0.3	1.9	0.0	2.3	4.1	3.1	2.4
Diploxylon	0.0	2.6	1.0	0.3	0.6	1.7	1.9	2.1	0.7
Undifferentiated pine	25.7	26.5	28.5	21.9	20.3	20.8	20.3	16.2	17.3
Cupressaceae	1.0	0.3	0.0	0.3	1.3	0.7	1.9	0.3	2.4
Quercus	1.6	0.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceanothus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cercocarpus	2.1	1.0	1.0	1.6	0.9	1.3	1.3	0.3	0.3
Rhamnus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephedra	0.5	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.3
Rosaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sarcobatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ambrosia	1.0	1.6	3.4	3.1	3.5	1.3	2.2	2.1	2.7
Artemisia	7.3	5.5	10.7	17.2	26.6	32.2	30.7	29.1	21.0
Cirsium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Compositae	0.5	1.3	0.7	0.9	2.5	0.3	2.8	1.2	2.0
Gramineae	0.0	1.0	0.7	0.6	1.6	0.3	0.0	0.6	1.0
Cheno-Ams	4.2	2.9	5.2	4.7	7.9	4.4	5.1	4.9	4.7
Cruciferae	2.1	1.6	1.4	0.3	1.3	2.3	1.6	1.5	4.7
Eriogonum	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.0
Ranunculaceae	0.0	0.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Leguminosae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Labiatae	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thalictrum	0.0	0.6	0.0	0.0	0.3	0.3	0.3	0.3	0.3
Euphorbiaceae	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	0.3	0.7	0.3	0.9	0.3	0.3	0.0	0.0
Betula	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
Salix	0.5	0.0	0.0	0.0	0.6	1.7	1.6	0.0	0.3
Cyperaceae	4.2	1.3	4.5	4.1	5.7	9.7	11.4	3.7	3.1
Polygonum-Type	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Typha latifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Umbelliferae	0.0	0.3	0.0	0.0	0.0	0.3	3.5	0.0	0.0
Pediastrum	0.0	2.9	26.1	113.5	366.8	46.3	23.4	5.5	0.7
Pollen Sum	191.0	310.0	291.0	319.0	316.0	298.0	316.0	327.0	295.0